U. S. GODAE: Global Ocean Prediction with the HYbrid Coordinate Ocean Model

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LONG-TERM GOALS

Use the HYbrid Coordinate Ocean Model (HYCOM) with data assimilation in an eddy-resolving, fully global ocean prediction system with transition to the Naval Oceanographic Office (NAVOCEANO) at 1/12° equatorial (~7 km mid-latitude) resolution in 2008 and 1/25° resolution in 2012. The model will include shallow water and provide boundary conditions to finer resolution coastal and regional models that may use HYCOM or a different model. In addition, HYCOM will be coupled to atmospheric, ice and bio-chemical models, with transition to the Fleet Numerical Meteorology and Oceanography Center (FNMOC) for coupled ocean-atmosphere prediction.

OBJECTIVES

(1) Develop a next generation eddy-resolving, fully global ocean prediction system using HYCOM with 1/12° equatorial resolution. (2) Transition this system to NAVOCEANO for operational use in 2008 with assimilation of sea surface height (SSH) from satellite altimeters, sea surface temperature (SST) and temperature (T)/salinity (S) profiles and the ability to perform skillful 30-day forecasts. (3) Include two-way coupling to an ice model. (4) Ensure that an accurate and generalized ocean model nesting capability is in place to support regional and littoral applications, including the capability to provide boundary conditions to nested models with fixed depth z-level coordinates, terrain following coordinates, generalized coordinates (HYCOM), and unstructured grids. (5) To facilitate this goal, develop HYCOM into a full-featured coastal ocean model in collaboration with a partnering project. (6) Participate in the multinational Global Ocean Data Assimilation Experiment (GODAE) and international GODAE-related ocean prediction system intercomparison projects.

APPROACH

This is a highly collaborative NOPP project with 24 partnering groups listed in the proposal. These partners are universities (with Eric Chassignet at the Florida State University as the overall lead PI), government (Navy and NOAA), industry and international. Additional partnering efforts are listed under related projects. The description of the approach focuses primarily on aspects performed at NRL-Stennis, many in close collaboration with project partners and partnering projects.

1. Ocean model design: HYCOM is a generalized (hybrid isopycnal/σ/z) coordinate ocean model. It is isopycnal in the stratified ocean, but reverts to a terrain-following (σ) coordinate in shallow depths, and to pressure (~z-level) coordinates in the surface mixed layer. The vertical coordinate is dynamic in space and time via the layered continuity equation, which allows a dynamical transition between the

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14. ABSTRACT
Use the HYbrid Coordinate Ocean Model (HYCOM) with data assimilation in an eddy-resolving, fully global ocean prediction system with transition to the Naval Oceanographic Office (NAVOCEANO) at 1/12? equatorial (~7 km mid-latitude) resolution in 2008 and 1/25? resolution in 2012. The model will include shallow water and provide boundary conditions to finer resolution coastal and regional models that may use HYCOM or a different model. In addition, HYCOM will be coupled to atmospheric, ice and bio-chemical models, with transition to the Fleet Numerical Meteorology and Oceanography Center (FNMOC) for coupled ocean-atmosphere prediction.

15. SUBJECT TERMS

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coordinate types. Like the Miami Isopycnic Coordinate Ocean Model (MICOM), HYCOM allows isopycnals intersecting sloping topography by allowing zero thickness layers. HYCOM was developed from MICOM using the theoretical foundation for implementing a hybrid coordinate system set forth in Bleck and Boudra (1981), Bleck and Benjamin (1993) and Bleck (2002). HYCOM was largely developed under an earlier NOPP project in a close collaboration between Rainer Bleck (Goddard Institute for Space Studies), Alan Wallcraft (NRL) and George Halliwell (University of Miami), the lead performer in each group. Alan Wallcraft is in charge of developing and maintaining the standard version of the model, one that is scalable/portable and can run on the latest computer architectures. HYCOM is maintained as a single source code with the maximum feasible backward compatibility.

2. Data assimilation techniques: Primarily, NRL-Stennis is using multi-variate optimum interpolation (MVOI) (Daley, 1991) in the Navy Coupled Ocean Data Assimilation (NCODA) system (Cummings, 2005), which was adapted for use in HYCOM in collaboration with O.M. Smedstad (Planning Systems, Inc.) and C. Thacker (NOAA/AOML). 3DVAR is a planned upgrade to NCODA, which also includes advanced data QC. The primary data types are SSH from satellite altimetry, SST and subsurface T & S profiles. Either the Cooper and Haines (1996) technique or synthetic T & S profiles (Fox et al., 2002) can be used for downward projection of SSH and SST.

3. Ocean model and prediction system configurations: The primary model domain is a fully global HYCOM configuration. It consists of a bipolar Arctic grid matched to a Mercator grid at 47°N. The resolution is .08°cosθ in latitude (θ) south of 47°N by .08° in longitude or ~7 km resolution for each model variable at mid-latitudes and 3.5 km at the North Pole. The array size is 4500 x 3298 with 32 hybrid layers in the vertical. The model is run with atmospheric forcing only and with data assimilation using a large FY05-08 DoD High Performance Computing (HPC) Challenge grant of computer time. A 1/12° Gulf of Mexico HYCOM configuration is the test bed for extensive testing of the NCODA system, including different options and modifications. A wide range of data sets are available for the evaluation (Chassignet et al., 2000; Hurlburt and Hogan, 2000) and these papers discuss many climatological model-data comparisons. In addition, we have long time series of transports through the Florida Straits, sea level at tide gauges, altimetric SSH, SST, subsurface T profiles from BTs and moored buoys, and T & S profiles from ARGO floats, some data obtained routinely and some from research field programs. Bill Schmitz (Woods Hole emeritus) is a part of the evaluation effort.

4. Boundary conditions for littoral and regional models (in collaboration with project partners and related projects): At NRL it includes a nesting capability for (1) HYCOM, (2) the Navy Coastal Ocean Model (NCOM) with σ-z coordinates, and (3) a baroclinic version of ADvanced CIRCulation (ADCIRC), the latter an unstructured grid model for baroclinic coastal/estuarian applications. NCOM is also a component of NRL-Monterey's regional Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™) (Hodur, 1997) and will be nested in HYCOM within COAMPS. See separate FY08 ONR Report.

5. GODAE: The project will participate in GODAE and the related prediction system intercomparison projects, e.g. the European MERSEA. The purpose of GODAE is to help justify a permanent global ocean observing system by demonstrating useful real-time global ocean products. Consistent with this goal, real-time HYCOM prediction system output is made available to the public via a 100 Tb Live Access Server (LAS) at Florida State. NRL is represented on the International GODAE Steering Team (IGST) by J. Cummings and H. Hurlburt.

WORK COMPLETED

A HYCOM special session was held in February, 2008 at the Ocean Sciences Meeting in Orlando, FL and a project meeting was held on the side. J. Cummings and H. Hurlburt represented NRL at the June 2008 IGST Meeting at NOAA/NCEP and each gave a presentation.

A fully-global 1/12° (~7 km mid-latitude) resolution configuration of the HYCOM/NCODA system is running in a pre-operational status at NAVOCEANO using operational queues. It began running daily in near real-time on 22 December 2006 and real-time on 16 February 2007, when a regularly scheduled operational queue was established. Thus, it became the first real-time eddy-resolving global ocean prediction system with high vertical resolution. Each day it performs a 5-day hindcast to pick up delayed data and it makes a 5-day forecast, the latter suspended since May, 2008 while facilities at NAVOCEANO are reconfigured for new computer systems. A 30-day forecast capability has also been demonstrated. Real-time and archived results for many subregions can be seen on the HYCOM web page, http://www.hycom.org, including model-data comparisons. In addition, results are included in Chassignet et al. (2008), Hurlburt et al., (2008), and Metzger et al. (2008). In the pre-operational mode, improvements in HYCOM/NCODA and the atmospheric forcing were implemented in the real-time run as soon as they passed testing. Global HYCOM is run with thermobaricity using a reference depth of 2000 m for potential density.

In collaboration with George Halliwell (U. Miami) HYCOM's hybrid grid generator, hybgen, was completely overhauled in FY08. Two higher order advection schemes, Piecewise Parabolic Method (PPM) and an enhancement to PPM that uses WENO-like interpolation for lower diffusion, were added as options for scalar fields and are always used for velocity. In addition the logic for handling adjacent layers (one too dense, the other too light) was modified to reduce the tendency for thin layers to form. Finally, the necessary switch back to the low order Piecewise Constant Method (PCM) (Donor Cell) for isopycnal layers was placed under run time control and is now typically not used for layers near the base of the mixed layer. These improvements were used in two climatologically-forced 1/12° global HYCOM simulations, but with the Piecewise Linear Method (PLM) (van Leer, 1977) selected for scalar fields and PPM for velocity. They were not used in other FY08 simulations (without data assimilation) either because they were performed prior to these improvements or for backward compatibility. Nearly all FY08 simulations use T and S advection (which is more physically accurate) rather than ρ (density) and S advection, as used in earlier simulations.

The implementation of tides (external and internal) into 32-layer, 1/12° global HYCOM was a major step forward in FY08. Tides are a NAVOCEANO requirement for the 1/25° global HYCOM prediction system planned for transition in 2012. This work was performed in collaboration with tide expert Brian Arbic at U. Texas. The implementation includes accurate self-attraction and loading plus topographic wave drag, both applied only to the tidal component of the circulation, the latter because topographic wave drag is different for oscillatory versus non-oscillatory motions (Bell, 1975). The oscillatory component was treated as the deviation from a 25-hour moving average. The tidal implementation was first tested in 1/12° global HYCOM barotropic and 2-layer baroclinic simulations, then in a 32-layer 1/12° global HYCOM simulation, all with M_2 tidal forcing only. This testing was followed by an interannual (July, 2003 – June, 2008) 32-layer, 1/12° global HYCOM simulation forced by 8 tidal constituents and winds plus thermal and moisture fluxes, making it the world's first eddy-resolving global ocean simulation with tides. The simulation with tidal forcing was designed for comparison with an otherwise nearly identical interannual simulation (Jan, 2003 – June, 2008)

simulation run earlier in FY08 without tides. The atmospheric forcing was from the Fleet Numerical Oceanography and Meteorology Center (FNMOC) Navy Operational Global Atmospheric Prediction System (NOGAPS) (on the .5° computational grid) with the wind speed scaled using a QuikSCAT analysis from Mark Bourassa at Florida State. It uses the newer bulk formulae of Kara et al. (2005) for wind stress and for the latent and sensible heat fluxes. The forcing was also corrected for land contamination (Kara et al., 2007). A strong effort on improving, evaluating and understanding the atmospheric forcing and its oceanic impact has continued, as evidenced in the publications list. All of the FY08 32-layer, 1/12° global HYCOM simulations were run on the Cray XT3 and XT4 at the Environmental Research and Development Center (ERDC) in Vicksburg, MS.

In FY08, significant effort went into improving the overall data assimilation methodology, e.g. improvements were made to the vertical remapping between the HYCOM first-guess in hybrid space to NCODA z-levels (the piecewise parabolic method was adopted). The technique based on Cooper and Haines (CH) (1996) for direct assimilation of observed SSH change was also modified. Examples include a new temperature-based definition of the HYCOM mixed layer, below which CH becomes active, and improved remapping from the NCODA analysis z-levels back to HYCOM hybrid space. In addition, work continued on implementing 3DVar in NCODA, but it is not yet ready for use in HYCOM. None of the simulations discussed above included ocean data assimilation. Those are discussed in the Chassignet et al. FY08 ONR Report for this project. However, 48 five-day forecasts, initialized from a data-assimilative 1/12° global HYCOM/NCODA hindcast (nowcast run in arrears), were run for evaluation of HYCOM short-range forecast skill (Metzger et al., 2008) and evaluations of data-assimilative HYCOM/NCODA nowcasting performance and HYCOM 30-day forecast skill are included in the next section.

The Los Alamos National Laboratory released the final version of CICE 4.0 (a sea ice model) to the community in late August 2008. We have successfully coupled CICE to a .72° Arctic Cap version of HYCOM using the Earth System Modeling Framework (ESMF). The system is currently being tested using 2003-2006 3-hourly 0.5° NOGAPS atmospheric forcing.

A methodology for one-way coupling of the continuous Galerkin baroclinic version of the finite element coastal model, ADCIRC, to HYCOM has been developed. Output from HYCOM is downscaled from its native structured horizontal and hybrid vertical grids to the baroclinic ADCIRC unstructured horizontal and σ-coordinate vertical grids. The methodology awaits evaluation of results.

RESULTS

Evaluation of ocean model simulations without data assimilation is essential because ocean model simulation skill is critical to dynamical interpolation skill in ocean data assimilation and to model forecast skill, the latter lasting ~1 month for mesoscale variability because it is largely a nondeterministic response to atmospheric forcing in deep water, except in the surface boundary layer. In addition, ocean model simulation skill is essential in representing ocean features that are insufficiently observed (e.g., mixed layer depth and other subsurface features) and for converting atmospheric forcing and topographic/coastline constraints into oceanographic information, critical in the surface boundary layer, shallow water and the equatorial wave guide (Hurlburt et al., 2008).

Hurlburt and Hogan (2008) provide a detailed dynamical explanation of Gulf Stream separation from the U.S. coast at Cape Hatteras, one that is strongly supported by a wide range of observational

evidence from both the upper and abyssal ocean. In particular, they found a key abyssal current that is driven by flow instabilities and guided by a low-amplitude topographic feature. This current and a Gulf Stream feedback mechanism determine the mean latitude of the Gulf Stream at 69°W. Between the coast and ~70°W they found that the Gulf Stream closely follows a specific inertial jet pathway, namely a Constant Absolute Vorticity (CAV) trajectory, a steady trajectory that is consistent with only a narrow band of high SSH variability along the Gulf Stream between the coast and ~70°W, as observed in satellite altimetry (Hurlburt and Hogan, 2008). Together the CAV trajectory and the latitudinal constraint at 69°W explain the Gulf Stream pathway in this region, while each alone is insufficient. Fig. 1a of the FY07 (Hurlburt, 2008) ONR report for this project depicts the best 1/12° global HYCOM simulation of the Gulf Stream pathway (without ocean data assimilation) in comparison to an observed 15-year mean Gulf Stream northwall pathway derived from satellite infrared (IR) imagery. This is a very good comparison in relation to the present state of the art (Bryan et al., 2007; Chassignet and Marshall, 2008), with the model pathway paralleling the observed pathway only slightly too far south where it separates from the coast. However, the results of Hurlburt and Hogan (2008) and the related observational evidence allow a more in-depth evaluation of the dynamics and performance of the model. This evaluation was performed as a team effort.

Despite a relatively good pathway (Fig. 1a), the dynamics of Gulf Stream separation from the coast in the HYCOM simulation are very different from Hurlburt and Hogan (2008) and inconsistent with the observational evidence. HYCOM exhibits a tight recirculation gyre south of the Gulf Stream that exhibits strong evidence of large amplitude flow instabilities, as indicated by (1) an associated broad area of high SSH variability versus a narrow band observed along the Gulf Stream pathway (Fig. 2) and (2) evidence of a mean abyssal gyre driven by baroclinic instability lying directly beneath the upper ocean gyre (Fig. 1b). This gyre is centered near 35°N, 72°W over the northwesternmost relatively flat area in the regional topography. Although the abyssal circulation does show some evidence of realistic features, it lacks the key abyssal current observed to flow generally southward beneath the Gulf Stream (south of the observed IR northwall) at 68°-69°W (Johns et al., 1995, their Fig. 2b). In addition, the speed at the core of the HYCOM Gulf Stream, near separation from the coast, is too low compared to observations and simulations used by Hurlburt and Hogan (2008). There are three major contributors to the strength of the Gulf Stream, (1) the wind forcing, (2) the Atlantic meridional overturning circulation (AMOC), and (3) a nonlinear inertial contribution, the third one depending substantially on the first two. A comparison of linear model response (Sverdrup, 1947 interior flow with Munk, 1950 western boundary layers) to the atmospheric forcing products used for HYCOM and by Hurlburt and Hogan (2008) shows the same western boundary current transport near the Gulf Stream separation latitude in both, but a more realistic pattern of flow, which should be more conducive to realistic Gulf Stream separation, from the wind forcing used with HYCOM. However, the AMOC in HYCOM is too weak (in nearly the same ratio as the HYCOM core current speed where the Gulf Stream separates from the coast) and the vertical structure of the Deep Western Boundary Current (DWBC) is unrealistic with the upper part too strong and the deep part too weak. That DWBC structure occurs because of an unrealistic distribution of deep water formation with too much in the Labrador Sea, too little in the Nordic Seas, and with too little entrainment as dense water flows over the Greenland-Scotland Ridge. These problems are very common in global ocean models. The NRL team is increasing its efforts to reduce the problems in collaboration with Eric Chassignet (NOPP project lead PI), project partner Bill Schmitz, and other NRL projects. Some key sources of these problems and a strong compounding feedback loop have been identified.

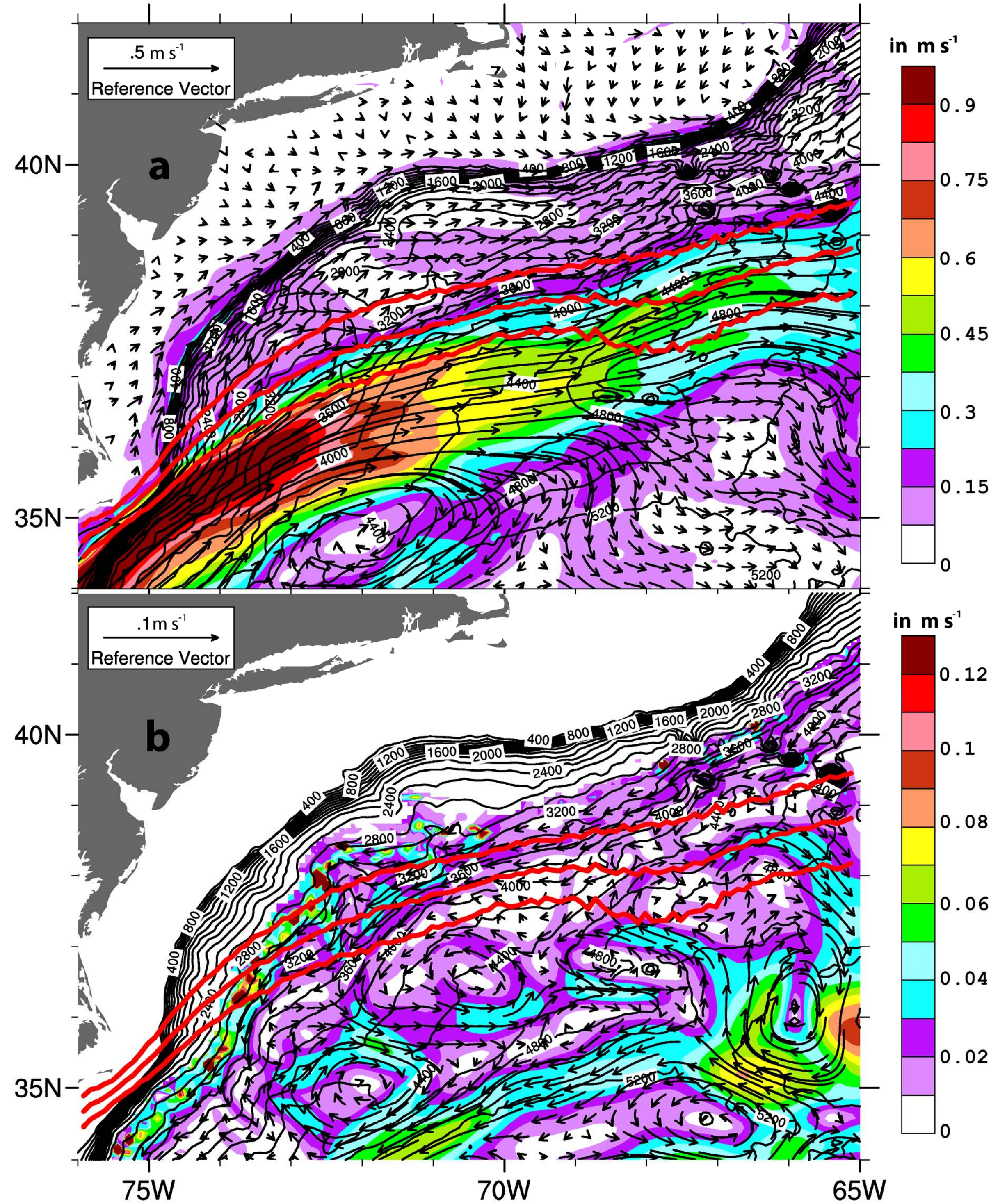

Fig. 1. Four-year mean currents (arrows) and current speed (in color) from a 1/12° global HYCOM simulation without ocean data assimilation, (a) from layer 6 at ~25 m depth and (b) layer 27 at ~3400 m depth. The simulation used climatological wind and thermal forcing derived from an ECMWF Reanalysis (ERA-40; Uppala et al., 2005) with the wind speed corrected using a QuikSCAT climatology. On each panel the black contours are ocean depth (in m) and the red lines are a 15-year mean Gulf Stream IR northwall pathway ± one standard deviation by Cornillon and Sirkes (unpublished).

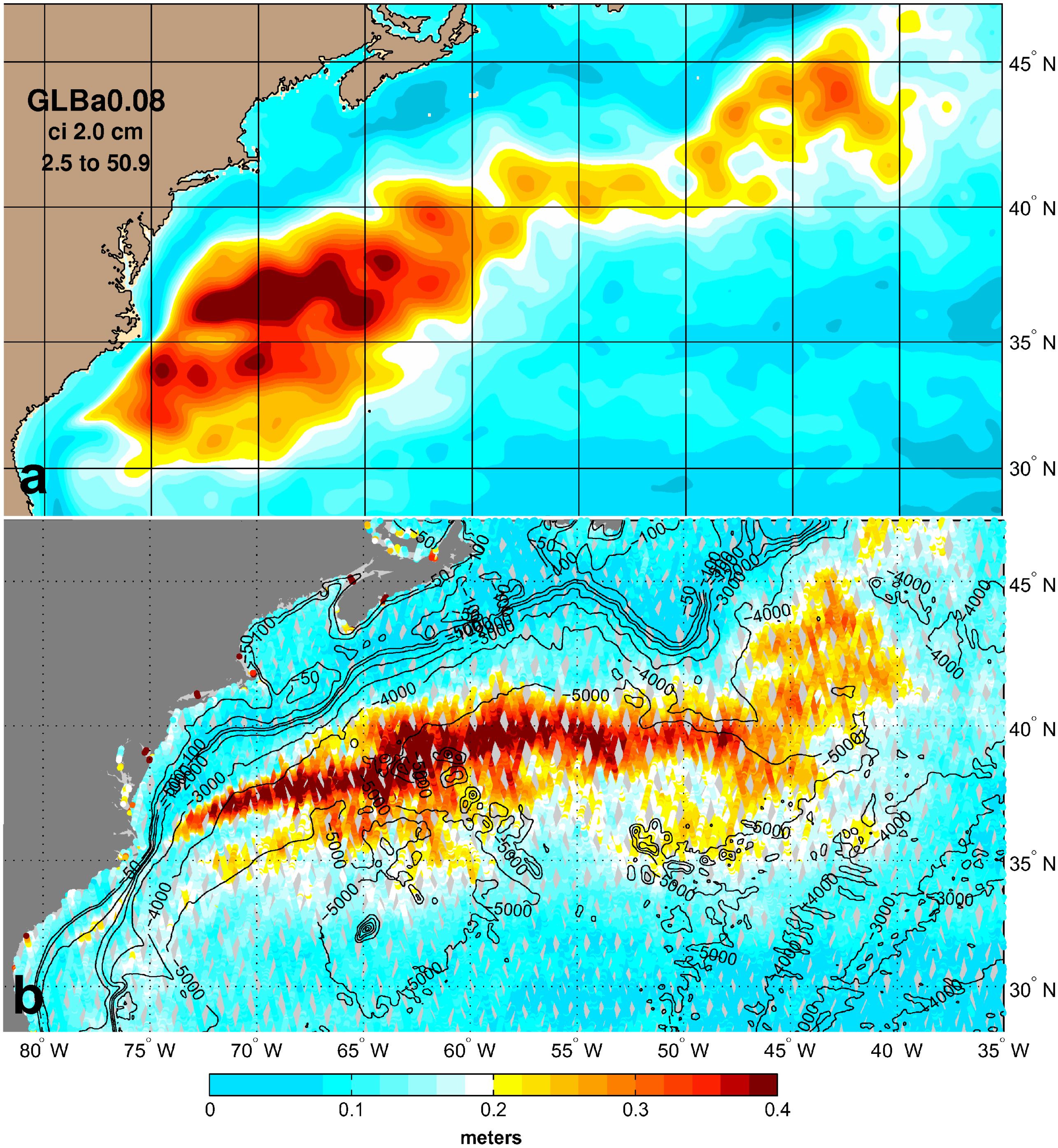

Fig. 2. (a) Root Mean Square (RMS) SSH variability over four model years from a non-assimilative 1/12° global HYCOM simulation using climatological wind and thermal forcing from the European Centre for Medium-Range Weather Forecasts (ECMWF) with wind speed corrected using a QuikSCAT climatology. (b) Quasi-contemporaneous along-track RMS SSH variability from satellite altimeter data in four orbits overlaid on topographic contours (depth in m). The tracks are overlaid in the following order from top to bottom: (1) Envisat, (2) GFO, (3) Jason-1, and (4) Topex interleaved. (b) is from Hurlburt and Hogan (2008) and was provided by Gregg Jacobs, NRL.

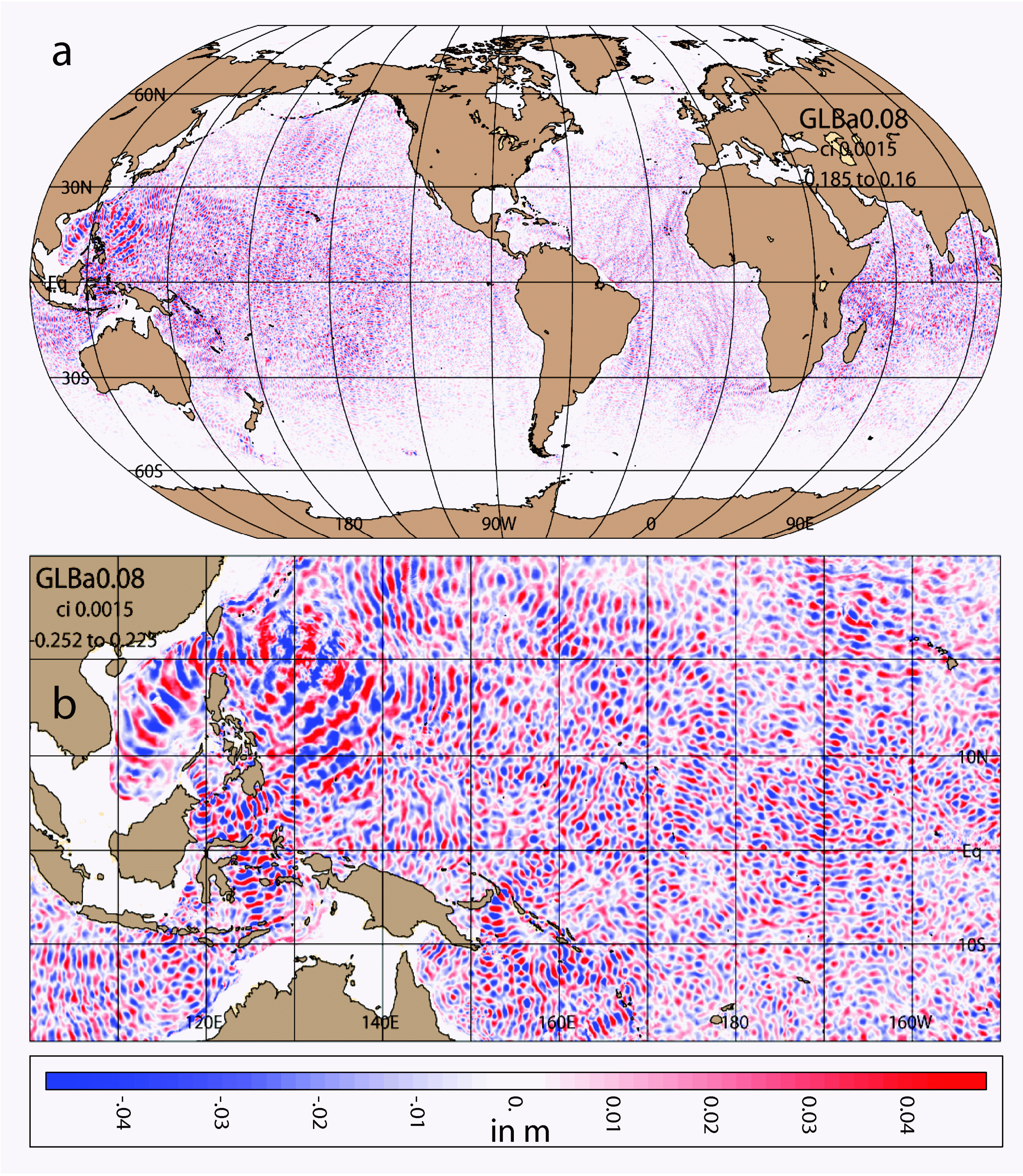

Fig. 3. 1/12° global HYCOM snapshot of internal waves generated by 8 tidal constituents as seen in SSH with the daily mean removed, (a) global and (b) a zoom on a Pacific subregion. The simulation also included forcing by winds and by thermal and moisture fluxes.

Fig. 3a shows a global snapshot of internal tides from a non-assimilative 32 layer, 1/12° global HYCOM simulation forced by 8 tidal constituents. The simulation is also forced by 3-hourly interannual winds plus thermal and moisture fluxes. Fig. 3b is a zoom on a low latitude Pacific region where the internal tides are relatively strong. In both panels tidal beams can be seen propagating for large distances, consistent with the theoretical work of St. Laurent and Garrett (2002), where beams of internal tides with spatial scales of 20 to 100 km propagate for distances of O(1000 km). Martin et al. (2006) found well defined beams of internal tides propagating away from topographic source regions, reminiscent of the features observed in the simulation. The internal tidal signature in SSH tends to be strong in deep water regions where both external tides and stratification are strong and weak in regions of low stratification or shallow water and in most semi-enclosed seas where tides tend to be weak, with the South China Sea and the interior seas of the Indonesian and Philippine archipelagos as notable exceptions. Over 10-20% of the world ocean tides are found to significantly impact the mean ocean circulation. Such impacts in this simulation are illustrated in the FY08 Hurlburt and Metzger ONR report for the PhilEx DRI project, “Flow through the straits of the Philippine Archipelago simulated by global HYCOM and EAS NCOM”.

As a consequence of the improvements to the NCODA data assimilation and the CH method for downward projection of SSH, results showed the assimilated observational inputs were more accurately ingested into the ocean model than before these modifications. However, error analyses based on comparison to unassimilated T & S profile observations indicated relatively large bias and root mean square error (RMSE) remained. This was traced back to a subsurface warm temperature bias in the non-assimilative HYCOM simulation used to initialize the assimilative system. Cummings (2005) notes a disadvantage of CH is that it cannot correct for model bias or long-term drift of water mass characteristics. Thus the second approach for downward projection was tested – assimilation of synthetic T & S profiles computed from the Modular Ocean Data Assimilation System (MODAS). These profiles are only created where the satellite based SSH anomalies with respect to the previous day’s ocean analysis exceed a user-defined value. Error analyses of the same unassimilated T & S profile observations using the MODAS approach yielded much smaller bias and RMSE than the CH approach (Fig. 4). Thus MODAS synthetics were chosen for the downward projection methodology. One disadvantage to the MODAS approach is that the system does not cycle on the HYCOM mean SSH, but rather utilizes the MODAS mean SSH. Attempts were made to modify NCODA to use the model mean SSH, but further work is needed and the MODAS mean is used in the system in transition to NAVOCEANO.

In the FY07 project report (Hurlburt, 2008), 1/12° global HYCOM 30-day forecast skill was verified against subsequent prediction system SSH nowcasts. Here we verify its SSH nowcast and 30-day forecast skill against an independent, unassimilated data set from coastal and island tide gauges, Fig. 5 for daily nowcasts against 147 tide gauge locations over the time period 1 June 2007 – 31 May 2008 and Fig. 6 against 114 tide gauges for twenty 30-day forecasts initialized from a hindcast during 2004 and 2005. In each case two forecasts were run, one using analysis quality atmospheric forcing and one using operational forcing that gradually reverts toward climatological forcing after 5 days. The forecasts demonstrate greater sensitivity to analysis vs operational quality atmospheric forcing at coastal stations than at island stations. That occurs because the ocean response to the atmospheric forcing is more deterministic at coastal stations and generally more non-deterministic in the ocean interior (Hurlburt et al., 2008).

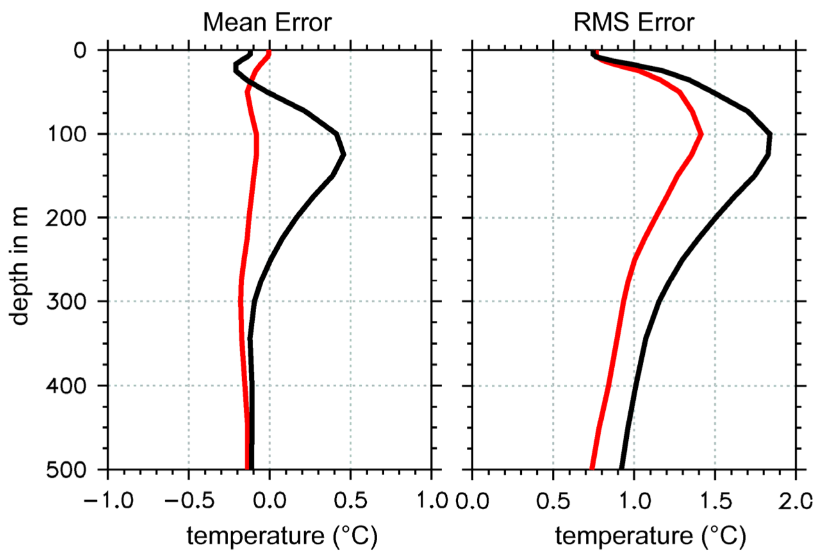

Fig. 4. Verification of data-assimilative 1/12° global HYCOM/NCODA nowcasts of temperature (°C) vs. depth in the top 500 m of the water column against ~8400 unassimilated profiles over the global ocean for the period June-July 2007. The left panel is mean error and the right panel is RMS error. The black (red) curve is the error between the unassimilated observations and temperature from 1/12° global HYCOM/NCODA that uses the Cooper and Haines (1996) (MODAS synthetics – Fox et al., 2002) method for downward projection of SSH (SSH and SST).

IMPACT/APPLICATIONS

HYCOM with data assimilation is in transition to an operational eddy-resolving, fully-global ocean prediction system. It will provide boundary conditions to finer resolution coastal/regional models that may use HYCOM or a different model. HYCOM is designed to make optimal use of three types of vertical coordinate, isopycnal, σ and pressure (~z-level). Isopycnals are the natural coordinate in stratified deep water, terrain-following (σ) coordinates in shallow water and z-levels within the mixed layer. The layered continuity equation allows a smooth dynamical space and time varying transition between the coordinate types. HYCOM permits isopycnals intersecting sloping topography by allowing zero thickness layers and it should allow accurate transition between deep and shallow water, historically a very difficult problem for ocean models. It also allows high vertical resolution where it is most needed, over the shelf and in the mixed layer. The isopycnal coordinate reduces the need for high vertical resolution in deep water. The project is represented by E. Chassignet (Florida State), J. Cummings (NRL) and H. Hurlburt (NRL) on the International GODAE Steering Team, a multinational effort designed to help justify a permanent global ocean observing system by demonstrating useful real-time global ocean products.

TRANSITIONS

A “Validation test report for the global ocean prediction system V3.0 – 1/12° HYCOM/NCODA: Phase I” (Metzger et al., 2008) has been completed via the 6.4 projects “Large Scale Prediction” and “Ocean Data Assimilation”. Based on the results in this report, NAVOCEANO has agreed that the 1/12° global HYCOM/NCODA prediction system is ready for transition to NAVOCEANO for formal operational testing, which is planned in 2009.

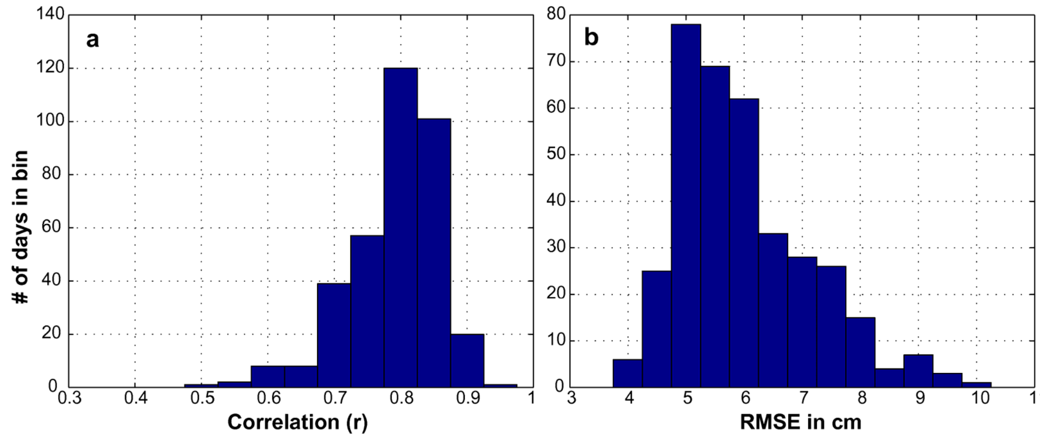

Fig. 5. Histograms of (a) correlation and (b) RMSE for 1/12° global HYCOM daily hindcasts vs. observed sea level during the period 1 June 2007 – 31 May 2008 at 147 tide gauge stations. The median correlation is .80 and the median RMSE is 5.8 cm. The statistics are computed ocean-wide for each daily hindcast. The ordinate indicates the number of days in each bin with bin increments of .05 for correlation and 0.5 cm for RMSE. (Adapted from Metzger et al., 2008)

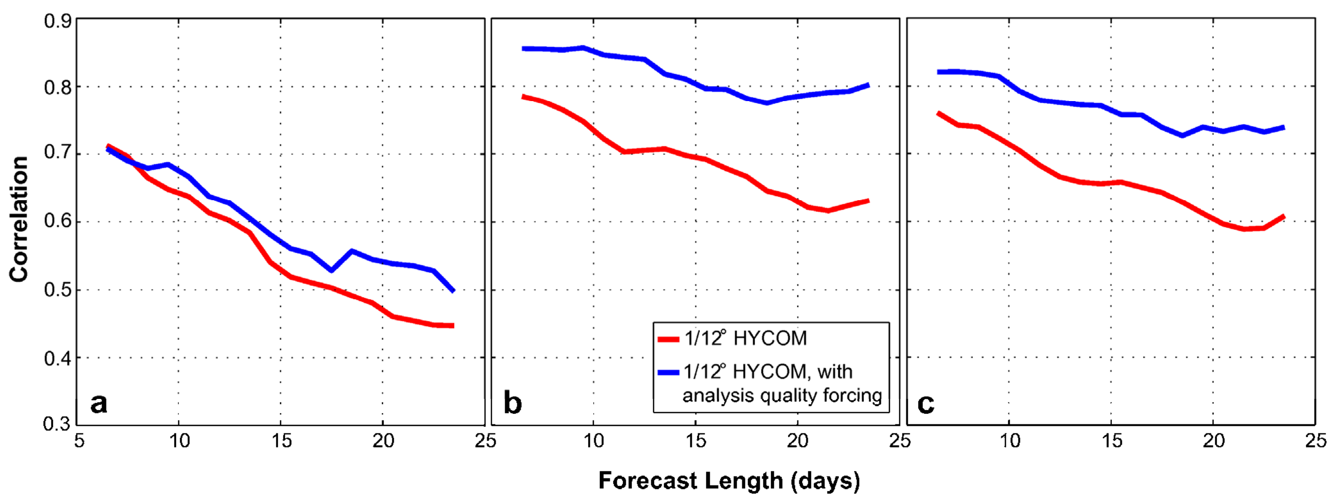

Fig. 6. Verification of 1/12° global HYCOM 30-day forecasts of SSH vs. unassimilated tide gauge data using 20 forecast periods initialized during 2004 and 2005, when data from three nadir-beam altimeters were assimilated by the hindcasts. The red curves verify 20 forecasts using operational atmospheric forcing that gradually reverts toward climatology after 5 days. The blue curves verify 20 "forecasts" with analysis-quality forcing for the duration. (a-c) show median correlation between forecast and observed fluctuations as a function of forecast length at (a) 23 open ocean island tide gauge stations, (b) 91 coastal tide gauges, and (c) all 114 tide gauge locations. A 13-day moving average was applied to filter time scales not resolved by the altimeter data. (Adapted from Hurlburt et al., 2008)

RELATED PROJECTS

This is a highly collaborative NOPP project with 24 partnering groups listed in the proposal. These partners are universities (with Eric Chassignet at Florida State as the overall lead PI), government (Navy and NOAA), industry and international. Partnering projects at NRL include 6.1 Global Remote

Littoral Forcing via Deep Water Pathways, the 6.1 PhilEx DRI project Flow through the straits of the Philippine Archipelago simulated by global HYCOM and EAS NCOM, 6.1 Dynamics of the Indonesian Throughflow (ITF) and its remote impact, 6.2 NOPP – HYCOM Coastal Ocean Hindcasts and Predictions: Impact of Nesting in HYCOM GODAE Assimilative Hindcasts, 6.3 Battlespace Environments Institute – ESMF for Atmospheric-Ice-Ocean Coupling and Component Interoperability, 6.4 Large Scale Ocean Modeling, and 6.4 Ocean Data Assimilation. Additionally, the project received grants of HPC time from the DoD High Performance Computing Modernization Office, including an FY05-08 HPC challenge grant entitled "Global Ocean Prediction using HYCOM" on the IBM SP4+ and SP5 at the Naval Oceanographic Office at Stennis Space Center, MS and on the Cray XT3 and XT4 at the Environmental Research and Development Center (ERDC) in Vicksburg, MS. This project is represented on the International GODAE Steering Team by E. Chassignet (Florida State), J. Cummings (NRL) and H. Hurlburt (NRL). See related ONR reports for this project by Chassignet at al. and by deRada.

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AWARDS

The "U.S. GODAE: Global Ocean Prediction with the HYbrid Coordinate Ocean Model (HYCOM)" project received the 2008 NOPP Excellence in Partnering Award presented by Senator Bill Nelson of Florida at the Hart Senate Office Building. Award criteria are partner diversity, level of effort/involvement, long-term commitment beyond the NOPP project, success in meeting project objectives, and the impact of the effort on the ocean research community. This ONR report represents a component of the project.